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RESEARCH ARTICLE

Analysis on the Land Suitability for Coconut Cultivation using Geographic Information System

Shirly Agcaoili[1]*

1 Researcher/Faculty-Agricultural Engineering Department, College of Engineering, Cagayan State University, Sanchez Mira, 3518, Cagayan, Philippines

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* **Corresponding author**.

shirly_agcaoili@yahoo.com

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Abstract

Objectives: This study developed a GIS-based approach for the spatial classification of land resources to assist planners to easily identify and increase areas for the cultivation of coconuts. **Methods:** The evaluation of land for its suitability application was a GIS-based multi-criteria evaluation involving guidelines on matching land quality diagnostics against crop requirements and assigning suitability rates for each land quality. Factors such as elevation, landform, soil drainage, slope, soil texture, and soil depth were used as parameters. **Findings:** Results showed that the existing coconut plantation is within the final suitability map developed. It revealed that around 420,000 hectares or 45.2% of the area considered in this study were found suitable locations for coconut production. **Applications:** Land suitability analysis for coconut cultivation using multi-criteria assessment in the GIS environment is a great tool for assessing and evaluating land in terms of its varying importance to decision-makers for sustainable agricultural production. **Novelty:** This study implemented spatial analysis in land evaluation that offered better land options in the study area.

Keywords: Land Suitability Analysis; Coconut Cultivation; Geographic Information System; Multiple Criteria; Spatial Analysis

1 Introduction

Despite the growing demand for coconut products, the Philippine Coconut Authority reports that the Philippines cannot meet the required volume of demand for coconut products. It becomes mandatory therefore for the Government to step in to meet this need.

In 2015, the Philippine Coconut Authority (PCA) has planted around 6 million coconut seedlings; yet this is 4 million short of the estimated 10 million coconut seedlings planted. The present situation presents a scenario that calls for an additional planting area and an efficient replanting program.

According to the PCA, region 2 was identified as suitable as a coconut growing zone but there are only 15,245 hectares planted with coconut. This shows the need to identify areas in the region to be planted with coconut to help achieve the national target of meeting the international demands for coconut products.

In 2001, a generalized map of coconut growing zones and production suitability levels was made, however; this was mainly based on rainfall levels, distribution, and growing altitude[1]. Further, throughout the decades, constant exploitation of land may have caused changes in land suitability and hence requires adoption of technological interventions to best identify ways for land use on basis of other essential factors used for land suitability assessment. The identification of possible locations for coconut cultivation considering other agronomic factors that could potentially affect the growth of crops is an essential step towards increasing plantation area for coconuts in specific areas. However, the usual method of identification of areas suitable for specific intervention consumes more time and requires lots of estimations on the part of implementing agency[2]. This calls for a need to conduct studies that considers other essential factors for land suitability assessment to assist in identifying the suitability which is a basis of sound land management. Technological developments applying GIS and other systems have been used widely to classify the suitability of lands[3] and these methods have been noted to reduce time and cost for decision-makers to achieve optimum utilization of land use[4]. Land suitability analysis is identifying the most suitable pattern for land use according to specific requirements and preferences[5]. In the geospatial realm, this suitability analysis has brought support for decision-makers to develop land resources at maximum[6] and identify areas with physical limitations for crop production[7,8].

To decide on suitability, several data have to be handled as inputs[7]. Geospatial technologies are capable of delineating potential land that are suitable for specific crop cultivation, time-saving and good data yielding according to various studies conducted[6,9]. Similarly, land suitability for agricultural applications includes efficient decisions at different levels[9], making the process of suitability analysis crucial for achieving optimum land use utilization[4].

Preparing land-use maps based from the land suitability analysis could be one of the most useful applications of the Geographic Information System (GIS) in planning and managing land recourses[10] and the application to agricultural purposes is the most important[11].

A geographic information system (GIS) is a computer-based tool commonly used in the process; as the system offers the flexibility, speed and power to synthesize large volume of data[12]. The potential of integrating GIS approach for quantitative land evaluation of land have been demonstrated earlier by several researches[13] for multicrop land suitability, for agricultural production[14,15] and[16] for cereals using AHP-GIS and remote sensing, . Many recent research studies have been carried out by scientist worldwide on the use of GIS on land suitability analysis for coconut[17–20], and for other crops like pigeon pea[21], banana and pineapple[22], and the results of these researches suggest the use of a GIS-based model for land suitability analysis for local scale. The present study was undertaken to demonstrate the usefulness of GIS technologies coupled with other agronomic factors to optimize and identify additional locations or areas for coconut production in the study area. The GIS-based approach could be used to develop a land suitability model for development and can be used as a policy tool in decision making for planning and development[23]. The output of this research could be used as a decision support framework in the direction of policy making especially in effectively identifying areas for coconut production.

Generally, this study developed a GIS-based model for identifying potential areas for coconut plantation and expansion in the province of Cagayan.

Specifically, it aimed to:

- Map potential identified areas for coconut production based on elevation, landform, land use, slope, soil texture, soil depth, and soil drainage
- Identify suitability criteria for coconut cultivation area
- Identify potential areas for coconut production areas in Cagayan
- Develop coconut cultivation suitability map of Cagayan

2 Methodology

2.1. Location and Topography of the Area under Study

Figure 1 shows the area (province of Cagayan) under study which is located at 18°14'56.2632" N and 121°52'43.6224" E[24]. The study area has a total land area of 9,295.75 square kilometres (3,589.11 sq. mi) which constitutes around three percent of the total land area of the country, making it the second-largest province in region 2. It is bounded on east by the Philippine Sea; the province of Isabela on the south; the Cordillera Mountains on the west, and the Babuyan group of Islands and the Balintang channel on the north. Palaui Island is approximately 2 kilometers (1.2 mi) from the north-eastern tip of the province; the Fuga Island is few kilometers to the west. Around 60 nautical miles (110km) north of the province is the Babuyan group of islands, which comprises Calayan, Dalupiri, Camiguin, and Babuyan Claro.

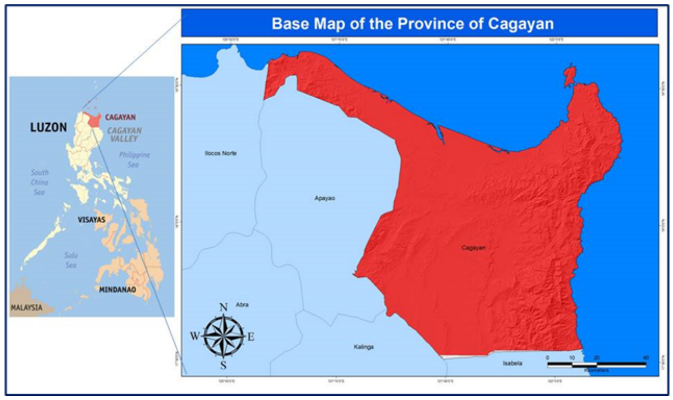

Fig 1. Location map of the study area

2.2 Soil

The major soil type in the province of Cagayan as shown in Figure 2 is clay loam. Some areas are dominantly clay, sandy clay loam, sandy loam, silty clay, silty loam, hydrosols, and mountain soils.

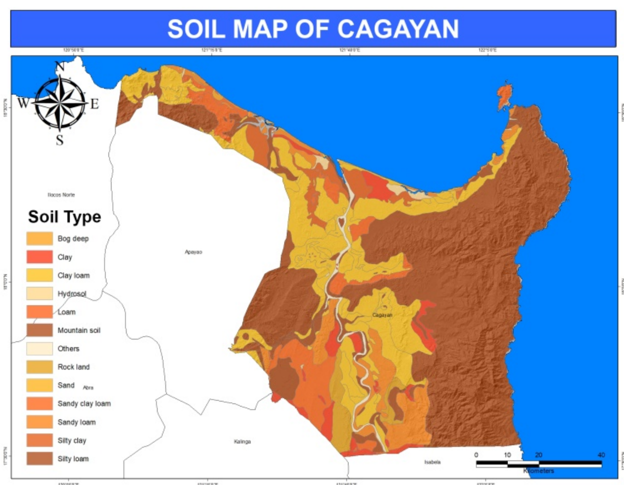

Fig 2. Soil map of the study area

2.3 Land Use

The land use of the province as shown in Figure 3 , includes cultivated lands, built-up areas, river beds grassland, wetland, and woodland area. The woodland land type is found in the eastern and mountainous parts of the province. Most of the cultivated lands are cropped with crops mostly grains and can be found in the central and western parts of the province. Other areas are classified as miscellaneous areas planted with mixed crops.

2.4 Data Requirements, Sources and Processes

To attain the objectives of the present study, different agronomic data types for land suitability of coconut cultivation were utilized. The different agronomic factors considered in the present study as suggested by the Philippine Coconut Authority include elevation, landform (geographical), soil drainage, slope, soil texture, and soil depth. Soil-related data were taken from the Department of Agriculture. Different data were collected and derived from different sources and GIS was used for making maps. Different shape files, digital elevation model, landform model soil drainage, slope, texture, and soil depth of the study

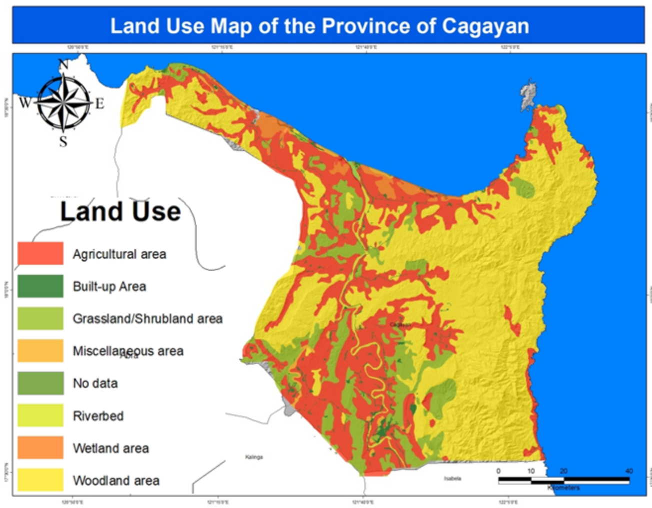

Fig 3. Present land-use map of the study area

area were extracted from a digitized elevation map (DEM).

The process of suitability analysis and mapping was based on evaluation criteria. Criteria were selected from available data based on PCA suggestions and different related literature,[25–29]. The criteria used for coconut cultivation land suitability analysis include elevation, landform, soil drainage, slope, soil texture, and soil depth suitability shown in Table 1 . The suitable site mapping was done using multi-criteria decision evaluation (MCDE). To carry out the MCDE, each criterion with its associated feature data is digitally encoded in the GIS database. A geo-database consisting of all factor layers was created in GIS software then point and line features were changed into raster data. Each layer was subjected to undergo reclassification process and weight. Then the overlay analysis was conducted using GIS spatial analyst extension. Finally, the land suitability for coconut cultivation map of the study area was produced.

Table 1. Land Suitability Criteria for Coconut Cultivation set for the Present Study

Factor	Description	Suitability Scale	Suitability Class
Elevation (m)	0-150 151-300 301-450 451-500	3 2 1 0	Highly suitable Suitable Fairly suitable Not suitable
Landform	Coastal flat/rolling Inland flat/rolling Coastal upland Inland upland	3 2 1 0	Highly suitable Suitable Fairly suitable Not suitable
Soil drainage	Naturally well drained Moderately drained Fairly drained Poorly drained	3 2 1 0	Highly suitable Suitable Fairly suitable Not suitable
Slope	Flat Moderately sloping Rolling Hilly	3 2 1 0	Highly suitable Suitable Fairly suitable Not suitable
Soil texture	Silty clay loam Clay loam Clayey Sandy	3 2 1 0	Highly suitable Suitable Fairly suitable Not suitable
Soil depth (cm)	> 91 81-90 76-80 71-75	3 2 1 0	Highly suitable Suitable Fairly suitable Not suitable

2.4.1 Elevation

Elevation affects largely the health, growth and development of plants. This factor may affect the type and amount of sunlight that plants receive, the amount of water readily available for the plants to absorb, and amount of nutrients that are available in the soil. According to PNS/BAFS 238:2018 standard[30], areas suitable for coconut production and processing should be with an altitude of 600 m or less above sea level to achieve optimal growth. The criteria set for the purpose of land suitability analysis for coconut cultivation are shown in Table 1. Areas with elevations ranging from 0-150 m above mean sea level (AMSL) are highly suitable; 151 – 300 m AMSL are suitable; 301-450 m AMSL are fairly suitable and areas with elevations above 450 m AMSL are not suitable for coconut cultivation. The elevation map of the study area is shown in Figure 4 a.

2.4.2 Landform

Available water in the soil is affected directly by the soil properties including soil texture and soil drainage characteristics. It affects the spatial variability of potential yields of plants [31]. These characteristics properties are dependent on the terrain characteristics. Inland suitability analysis for coconut, coastal flat/rolling landforms are characterized as highly suitable; inland flat/rolling landforms are suitable; coastal upland landforms are fairly suitable; inland upland landforms are not suitable for coconut cultivation. The landform map of the study area is shown in Figure 4 b.

2.4.3 Slope

The slope is one of the factors considered in determining the suitability of an area for coconut production. This factor may influence land development, irrigation, erosion hazard, drainage requirement, and other management and production costs. In this study, areas of flat slopes are considered highly suitable; moderately sloping areas are considered suitable; rolling areas are fairly suitable; hilly areas are considered not suitable for coconut cultivation. The slope map of the study area is shown in Figure 4 c.

2.4.4 Soil Texture

Soil texture, in the strictest sense, is the relative proportion of sand, silt, and clay [32,33]. Soil texture is an important soil characteristic that influences storm water infiltration rates. The texture of the soil determines the rate at which water drains through a saturated soil; water moves more freely through sandy soils than it does through clayey soils. Soil texture indirectly affects plant growth through its influence on soil water supply [34], and on the supply of nutrients such as nitrogen [35]. In this study, soil textures of silty clay loam are considered highly suitable; soil textures of clay loam are considered suitable; clayey soil textures are characterized as fairly suitable, and sandy soils are characterized as not suitable for coconut production as shown in Table 1. The soil texture map of the study area is shown in Figure 4 d.

2.4.5 Soil Drainage

Soil drainage through the root zone is one of the most important physical properties of soil for it significantly affects the production of crops. It determines which types of plants grow best in an area. It affects the growth of plants, water transmission, and solute conveyance in soils including environmental components such as irrigation and soil reclamation, capability of the land for agriculture, flood control systems, engineering, and health [36]. This characteristic significantly influences aeration in the rooting zone, and the amount of aeration significantly affects some important biochemical reactions of economic importance to crop production [37]. The drainage requirement for coconut is characterized as moderate to well-drained [38]. The four (4) soil drainage classes shown in table 1 are used in the study to determine the land suitability of an area for coconut cultivation. The soil drainage map of the study area is shown in Figure 4e.

2.4.6 Soil Depth

The soil depth is one of the major factors in the assessment of land suitability for coconut cultivation. Its primary purpose is in the productive capacity, but it may also influence production and development costs. The minimum soil depth for coconut cultivation is greater than 75 cm [30]. Soil depth determines the potential rooting depth of plants to be grown and any restrictions within the soil that may hinder rooting depth. A crop may require 3 to 4 feet. Any discontinues in the soil from layers of sand, gravel or even bedrock can physically limit rooting depth and hinders irrigation. The soil type classification considered in this study to determine the suitability of soil depth for coconut cultivation is shown in Table 1. The soil depth map of the study area is shown in Figure 4 f.

2.5 Analysis and Identification of Potential Areas for Coconut Cultivation

The flowchart showing the methodology adopted for coconut cultivation land suitability is shown in Figure 5. In this process, the land-use map, elevation map, landform map, soil drainage map, slope map, soil texture map, and soil depth map were used.

The land use map (Figure 3) was used to determine present land use in the study area. Areas in the study area based on the present land-use map that are classified as built-up areas, river beds, wetlands, and woodland/forest reserved were clipped out of the map before suitability analysis. This means that these areas were not included in the analysis and thus considered as areas not suitable for coconut cultivation. The spatial distribution of import data sets shown in Figure 4, was selected as factors and collected from different sources.

The suitability scale for each factor is shown in Table 1. The weight for each factor is shown in Table 2.

The overall suitability was determined using weighted overlay analysis in a GIS environment.

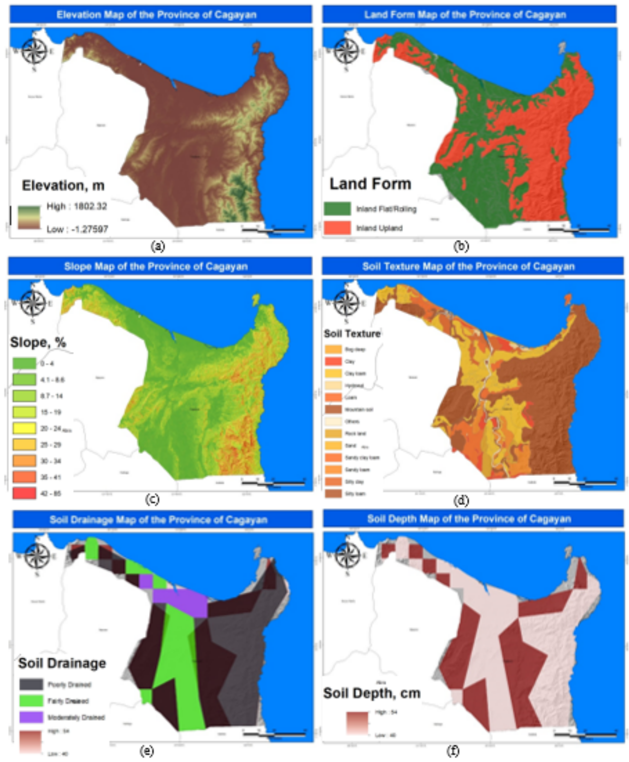

Fig 4. The different maps of the study area used for the land suitability for coconut cultivation (a) elevation map, (b) land form map, (c) slope map, (d) soil texture map, (e) soil drainage map, (f) soil depth map

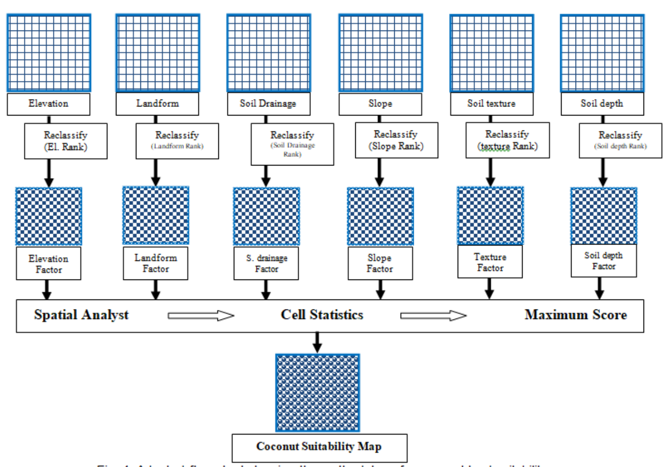

Fig 5. Adopted flow chart showing the methodology for coconut land suitability map

Table 2. Coconut Land Suitability Factors and each factor weights

Factor	Suitability Scale	Suitability Weight
Elevation (m)	0-3	16.7%
Landform	0-3	16.7%
Soil Drainage	0-3	16.7%
Slope	0-3	16.7%
Texture	0-3	16.7%
Soil depth (m)	0-3	16.7%

Land suitability (LS) for the coconut cultivation model was derived from combining the factors with their corresponding weights for determining the potential areas for coconut cultivation. Equation 1 was used in calculating the suitability value in each cell:

$$LS = \sum \text{(suitability criteria x suitability factor)} \tag{1}$$

The suitability scale of each factor was multiplied by each respective suitability weight (Table 2) and came up with the suitability map. The elevation map, for instance, the elevation map was categorized as highly suitable, suitable, fairly suitable, and not suitable for a suitability scale of 3, 2, 1, and 0, respectively. These suitability scales were multiplied by the suitability weight for elevation which is equal to 0.167. The procedure was done for the other factors and the output map was the land suitability map for the coconut map.

3 Results and Discussion

3.1. Overlaying Map Layers and Analysis

After setting the weights of the criteria in the present research through discussions among related experts and literature reviews, the entire criteria maps were overlaid through the use of the GIS function and the suitability maps were prepared for the main criteria. The main suitability maps went through weight overlaying and the final map of land suitability for coconut cultivation was produced. The results integrate the assigned weights of each criterion with the criteria of the maps with the raster calculator function in ArcGIS software.

Land suitability maps of the study area according to different aspects of elevation, landform, soil drainage, slope, soil texture, soil depth and land use are demonstrated in Figure 6. The final land suitability map resulting from the final weighted overlay is shown in Figure 7.

Based on the final suitability map (Figure 7), the study area was classified as highly suitable, suitable, fairly suitable, and not suitable. The classified map indicates that 10.09% (93,783 ha) of the study area is highly suitable, 35.07% (326,046 ha) of the area is suitable, 11.36% (105,560 ha) of the area is fairly suitable, and 43.48% (404,211 ha) is unsuitable for coconut cultivation as shown in Table 3. With the result of the analysis of the study area, 45.16% (419,828 ha) is either highly suitable or suitable for coconut cultivation. After comparing the existing areas in the study area currently cultivating coconuts and the land suitability map, most of the coconut is currently cultivated in the area. Thus, it is recommended to cultivate coconut in the areas identified in the study as highly suitable or suitable for coconut cultivation, and other crops may be considered to be planted in areas identified as fairly suitable for coconut cultivation. The unsuitable areas are characterized as built-up areas, river beds, wetlands, and woodland/forest reserved. This implies that if all the areas identified as highly suitable and suitable be planted with coconut, then the coconut plantation area in the study area will be increased. Consequently, the coconut production of the province would further increase its coconut production and increase its national contribution to supplying the demands of the country and exportation demands.

Indeed, employing GIS for suitability analysis allows decision makers identify the main limiting factors for agricultural production which enables them to develop better management to increase land productivity[(39–41)], land use efficiency[(42)] and crop production[(43)].

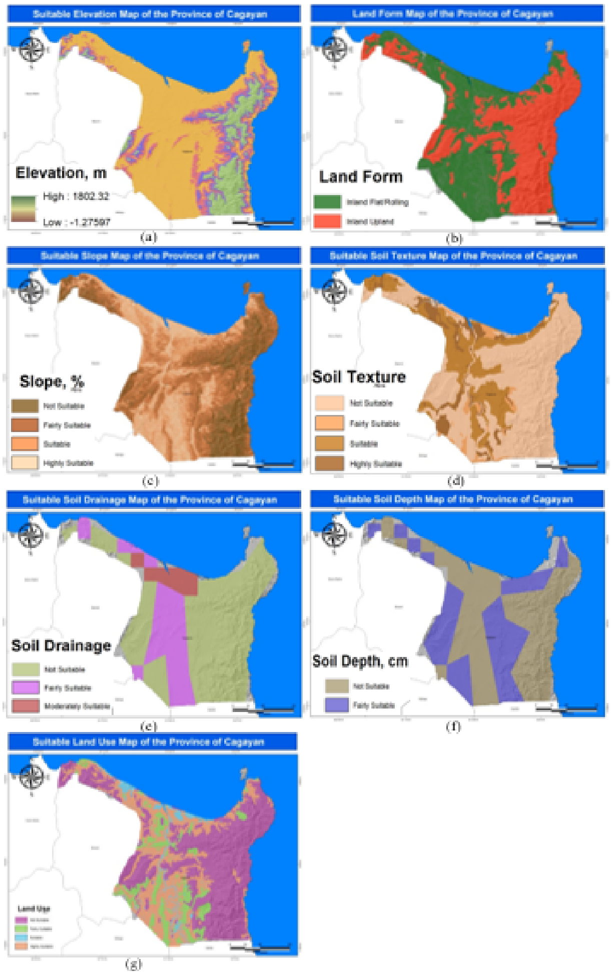

Fig 6. Suitability maps based (a) elevation, (b) land form, (c) slope, (d) soil texture, (e) soil drainage, (d) soil depth, (e) land use

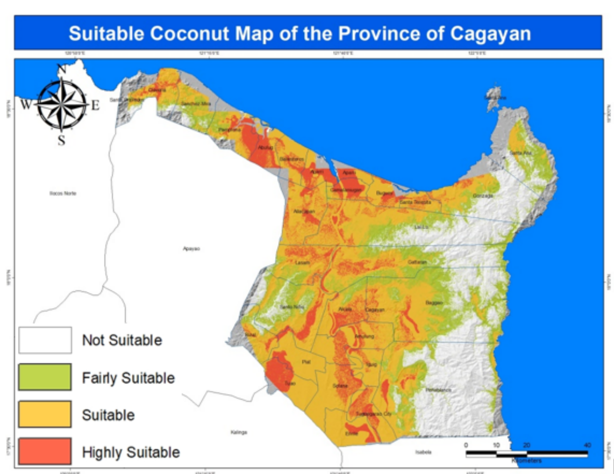

Fig 7. Land Suitability Map for Coconut Cultivation

Table 3. Distribution of areas according to Land Suitability Analysis for Coconut Cultivation

Level of Suitability	Area of Coverage (ha)	Percent (%) of the Total Area
Highly suitable	93,783	10.09%
Suitable	326,046	35.07%
Fairly suitable	105,560	11.36%
Not suitable	404,211	43.48%
Total	**929,600**	**100%**

4 Conclusion

Based on the result of the analysis, the following conclusions were drawn;

• The potential suitable area identified is characterized by an elevation ranging from 0-300 m, a landform of coastal/inland to rolling areas, moderately to well-drained soil, moderately sloping to flat areas, with a soil texture of silty clay loam to clay loam soil, and with a soil depth of greater than 90 cm.

• The suitability criteria used in the study coincide with the criteria of the existing coconut plantation such as elevation, landform, soil drainage, slope, soil texture, and soil depth as manifested by most of the existing coconut plantation areas within the suitable area identified in the study.

• The methods used in the study could be beneficial to prioritizing the lands for coconut cultivation and it could also improve exploitation and protect the resources and sustainable management.

• The result of this study could provide useful information on selecting a proper cultivation pattern in other places since it considers many agronomic factors for coconut cultivation.

Future Scope

The study could be used as a sound basis for crop suitability analysis and planning in other places in the future.

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